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THE TAXONOMY, DISTRIBUTION AND INTRODUCTION HISTORY OF THE EARLIEST REPORTED ALIEN FRESHWATER MOLLUSC IN SINGAPORE — SINOTAIA GUANGDUNGENSIS (GASTROPODA: VIVIPARIDAE)

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INTRODUCTION

Freshwater fauna introductions in Singapore
have been relatively well documented (Yeo
& Chia, 2010), but the origins of many alien species, such as freshwater molluscs are un-confirmed (Tan et al., 2012). Among the known introduced molluscs, the South American Poma-cea canaliculata is perhaps the most notorious owing to it being a widespread and major agricul-ture pest (Joshi & Sebastian, 2006). However, P canaliculata is a relatively recent introduction to Singapore (since 1980s; Tan et al., 2012) compared to Sinotaia guangdungensis (Kobelt, 1906) (Viviparidae), which was first recorded in the 1950s (as Vivipara polyzonata by Johnson, 1957), making itthe earliest reported introduced freshwater mollusc here.
The taxonomy of Sinotaia guangdungensis has been confusing, resulting in the species being referred to by different names. Following Johnson (1973), the species has been known in Singapore as Angulyagra polyzonata (and subsequently as Taia polyzonata in Clements et al., 2006; Tan et al., 2012); however, the name Taia polyzonata appears to have been used almost exclusively in Singapore and neighbouring Malaysia (e.g., Palmieri et al., 1980; Sengupta et al., 2009; Tan et al., 2012). Shea (1994) re-identified the species in Singa-pore as Bellamya heudei guangdungensis, by differentiating it from Angulyagra polyzonata, and although Shea’s correction was noted by Chan (1997), this name has been overlooked in Singapore to date.
Sinotaia guangdungensis is rarely docu-mented in its native region in southern China (Shea, 1994) and little else is known about the species. Therefore, an account based on specimens collected in Singapore can con-

tribute to informing and guiding future efforts to resolve the taxonomic and biogeographic confusion associated with this species and with the Viviparidae in general. Additionally, a record of its introduction history can also be useful in elucidating freshwater biological introductions to Singapore. In this research note, we review the taxonomy of Sinotaia guangdungensis, its current distribution in Singapore, as well as its known distribution within its invaded range, and the likely origins of the introduced population. Records from the Zoological Reference Col-lection (ZRC) of the Lee Kong Chian Natural History Museum (formerly Raffles Museum of Biodiversity Research), National University of Singapore; published literature; and unpub-lished data were consulted. Singapore material was also compared to photographs of type material from Senckenberg Forschungsinstitut und Naturmuseum, Frankfurt, Germany, and the Naturhistorisches Museum Wien, Austria.

SPECIES ACCOUNT

Family Vivipariidae Gray, 1847
Genus Sinotaia Haas, 1939

Type species: Paludina quadrata Benson, 1842 (type locality: Chusan, China).

Sinotaia guangdungensis
(Kobelt, 1906)
(Fig. 1)

Vivipara (quadrata var.) heudei var. guang-
dungensis Kobelt, 1906: 124-125, pl. 21,
fig1s2, .14 .
Dactylochalamys quangdugensis [sic] — Pra-
shad, 1928: 169.

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Vivipara polyzonata — Yen, 1939: 37, pl. 3, figs.
14, 15 [non Frauenfeld, 1862].
Angulyagra quangdungensis — Yen, 1943: 128. Sinotaia polyzonata — Zilch, 1955: 77 [non Frauenfeld, 1862].
Vivipara polyzonatus — Johnson, 1957: 65 [non Frauenfeld, 1862].
Taia polyzonata — Johnson, 1973: 120, 122; Palmieri et al., 1980: 40; Ng, 1991: 125; Chan, 1996: 184—185, fig. 2; 1997: 35; Maas-sen, 2001: 44: Clements et al., 2006: 144: Tan & Woo, 2010: 26; Yeo & Chia, 2010: 32; Tan et al., 2012: 133 [non Frauenfeld, 1862]. Sinotaia quadrata guangdungensis — Brandt, 1974: 30.

Viviparus polyzonata — Ng et al., 1993: 20 [non Frauenfeld, 1862].
Bellamya heudei guangdungensis — Shea, 1994: 3-11.

Material Examined

Singapore: Jurong Road, 11 % miles: ZRC1989.118; ZRC1989.1181-1989.1183, 20 Jul. 1960. Кап Teck Road: ZRC1989.1184—
1989,.1185,,2> Jun. 1961. Potong. Pasir:
ZRC1989.1186-1989.1190, 27 Jun. 1962.
Buona Vista, pond: ZRC1989.1191-1989.1202,
20 Nov. 1957; ZRC1989.1220-1989.1231, 11
Nov. 1958; MacRitchie, Sungei Whampoa:

FIG. 1. Sinotaia guangdungensis from Singapore. (A): Aspecimen from Jurong Lake; (B): Alive speci-men from Lower Seletar Reservoir; (C): Mantle edge of a specimen from Sungei Seletar. Photographs by Ting Hui Ng (A& C) and Siong Kiat Tan (B).

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ZRC1989.1203-1989.1209, 16 May 1962. University of Malaya, Botany Department tank: ZRC1989.1210-1989.1219, 25 May 1968. Ju-rong Road, pond: ZRC1989.1232-1989.1253, 23 May 1962; ZRC1989.1254-1989.1261, 21 Мау 1962; ZRC1989.1262-1989.1280, 23 May 1963. Potong Pasir, pond: ZRC1989.1281- 1989.1307, ZRC1989.1332-1989.1339, 2 Jul. 1962. Sungei Whampoa: ZRC1989.1308— 1989.1331, ZRC1989.1344-1989.1826. Sele-tar Reservoir (currently known as Upper Seletar Reservoir): ZRC1989.1340-1989.1343, 4 Feb. 1981; ZRC1990.868-1990.872, 11 Mar. 1990; ZRC1999.1398, 1 Feb. 1999; ZRC.MOL.21- 22, 4 Jun. 2002. Vaughan Road, pond: ZRC1989.1837-1989.1841, 27 Jun. 1963. Hol-land Road: ZRC1989.1942-1989.1943. Lower Peirce Reservoir: ZRC1990.738-1990.829, 29 Nov. 1990; ZRC.MOL.19, 8 Aug. 2002. Jurong Lake: ZRC1991.19290-1990.19308, 16 Apr. 1991; ZRC.MOL.20, 11 Jul. 2002. Nee soon Road: ZRC1995.672, 10 Jun. 1995. Lower Seletar Reservoir: ZRC.MOL.18, 24 May. 2002; ZRC.MOL.2931, 19 Feb. 2009. Kranji Reservoir: ZRC.MOL.17, 7 Jul. 2002. Un-known localities: ZRC1989.1827-1989.1834; ZRC1989.1835-1989.1836; ZRC1989.1842- 1989.1865.

Description

Shell ovately conic, spire turreted, base rounded, usually less than 25 mm in shell height, thin but solid; shell colour yellowish green to light greenish brown, spiral ribs red-dish brown to dark brown, aperture and parietal callus white to orange; whorls 6-7, slightly convex in profile, suture slightly impressed, body whorl round in profile without prominent angle at periphery, space between ribs slightly concave, ribs usually 3 above periphery and spire whorls, usually much weaker after the first rio below the periphery; aperture subovate, columella thickened and reflected over the umbilical area, umbilicus absent, parietal wall usually callused.

Geographic Distribution

Sinotaia guangdungensis appears to origi-nate from Guangdong and Guangxi provinces in southern China, and from Hong Kong (Shea, 1994). It has been introduced to Australia, Malaysia and Singapore (Shea, 1994; Chan, 1997; Tan et al., 2012).

TAXONOMY AND NOMENCLATURE

Vivipara guangdungensis was described by Kobelt (1906: 124-125, pl. 21, fig. 12) as an unusual form of Vivipara heudei, itself described as a variety of Paludina quadrata Benson, 1842, by Dautzenberg & Fischer (1905), from Guang-dong (“Guangdung’) province in China (Fig. 2). Confusion over the identity and validity of Vi-vipara guangdungensis seems to have started when Yen (1939) mistakenly synonymised this species with Vivipara polyzonata Frauenfeld, 1862 (Yen, 1939; Brandt, 1974; Shea, 1994; Fig. 3). Although Yen (1943) subsequently re-stored both as separate species, Zilch (1955) appears to have overlooked Yen’s publication and maintained the synonymy in his catalogue of the viviparid type material in the Senckenberg Naturmuseum. The type material of V. polyzo-nata, however, is composed of two species (see Fig. 3; Shea, 1994) and may continue to con-found future taxonomic studies if not resolved. As also noted by Shea (1994: 8), at least two of the paralectotypes (NHMW68038) are actually Vivipara guangdungensis (Fig. 3).
Prashad (1928: 169) disagreed with Kobelt (1906) that Vivipara quangdugensis [sic] was related to Vivipara quadratus var. heudei, and instead suggested that it was a distinct species of the genus Dactylochlamys Rao, 1925 [non Lauterborn, 1901]. Rao (1925) established the genus Dactylochlamys for Paludina oxytropis Benson, 1836, and described it as having promi-nent “finger shaped processes” along the mantle edge, a feature missing from the species dis-cussed here (Fig. 1C). However, Dactylochlamys was a preoccupied name, and so Rao (1931:
301) subsequently proposed Angulyagra as a replacement. We concur with Prashad (1928) that guangdungensis represents a species distinct from heudei, but follow Brandt (1974) in assigning it to the genus Sinofaia Haas, 1939. The description for the genus Sinotaia agrees well with the species: “...characterized by the narrow, rather thick shell with an expanded columellar thickening, mostly blackish towards its outer margin, and by the indication or strong development of keels on the upper, middle, and lower part of the whorls” (Haas, 1939: 96). The species in Singapore was apparently first identified by the prominent malacologist R. Tucker Abbott as Vivipara polyzonata Fraun-feld; but this identification was doubted by D. S. Johnson owing to the mistaken belief that V. polyzonata was a Mediterranean species

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FIG. 2. Vivipara guangdungensis Kobelt, 1906, ho-
lotype (SMF38890), Canton, China. Photographs
by Eike Neubert; courtesy of Ronald Janssen, Mollusc Section, Senckenberg Forschungsinstitut
und Naturmuseum Frankfurt, Germany.

(Johnson, unpublished manuscript). Nonethe-less, Johnson continued to apply the names Vivipara polyzonata, and Taia polyzonata (e.g., Johnson, 1957, 1973), and the name Тала po-lyzonata continued to be used in Singapore up

to now (Tan & Woo, 2010). Shea (1994) was the first to correctly identify the species found in Singapore as Sinotaia guangdungensis (as Bellamya heudei guangdungensis), and detailed its taxonomic history. All material from Singapore that we examined, and verifiable records in the literature conform to the descrip-tions and conchological characteristics of the holotype of Sinotaia guangdungensis (Fig. 2; Kobelt, 1906; Shea, 1994), and no Angulyagra polyzonata was located. It is therefore very likely that all previous Singapore records of Angulyagra polyzonata — alternatively repre-sented in the literature as Vivipara polyzonatus, Viviparus polyzonata, and Taia polyzonata — are misidentifications (see synonymy for Sinotaia guangdungensis).

DISTRIBUTION AND HABITATS IN
SINGAPORE

In the early reports of Sinotaia guangdungen-
sis in Singapore, it was found to be common in
fish breeding ponds (as Vivipara polyzonatus in
Johnson, 1957; as Taia polyzonata in Johnson,

FIG. 3. Types of Vivipara polyzonata Frauenfeld, 1862. (A): Lectotype (NHMW68037), designated by Yen (1939); (B-D): Paralectotypes (NHMW68038) [B, D = Sinotaia guangdungensis], (В) locality marked as “China?”, (C, D) accompanied by multiple labels with no clearly identified locality information. Photographs by Alice Schumacher; courtesy of Anita Eschner, Collection Mollusca, Naturhistorisches Museum Wien, Austria. Scale bar = 10mm.

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FIG. 4. Current distribution of Sinotaia guangdungensis in Singapore. JL (Jurong Lake and tributaries), KJ (Kranji Reservoir and tributaries), LP (Lower Peirce Reservoir), LS (Lower Seletar Reservoir and tributaries), WC (Western Catchment Reservoirs: Tengeh, Poyan, Murai, Sarimbun), US (Upper Seletar Reservoir), BP (Bishan Park canal).

1973). Established populations were recorded
from such ponds around the island (Buona
Vista, Jurong Road, Potong Pasir), and also
from canals and ditches (Sungei Whampoa,
Lorong Buang Kok) (Ponniah, 1962; Johnson, unpublished manuscript). There is a gap in published records of the species in the 1970s and 1980s, after Johnson — who had led much of the research on freshwater invertebrates at the then University of Singapore — passed away in 1972 (Harding, 1974). Collections of freshwater molluscs mainly resumed in the 1990s.
By the 1990s, most of the fishponds had disap-peared, and other types of artificial freshwater habitats had become more dominant, with most of Singapore's rivers being impounded in the 1970s and 1980s to create reservoirs through-out the island (Yeo et al., 2010). Freshwater molluscs soon established in these reservoirs, including Sinotaia guangdungensis, which was found in five reservoirs by the early 2000s — Up-per Seletar, Lower Seletar, Lower Peirce, Kranji, and Jurong Lake (Fig. 4; Ng, 1991; Clements et al., 2006; Tan et al., 2012). The species is now

also established in four more reservoirs in the Western Catchment area of Singapore, and in various waterways connected to reservoirs, for example, Sungei Jurong (connected to Jurong Lake), Sungei Seletar (Lower Seletar), and the main stream in Bishan Park (Lower Peirce) (T. Н. N., pers. obs.). Although widespread, Sinotaia guangdungensis seems to avoid hard-bottomed concrete canals, unlike common molluscs like Pomacea canaliculata (S. К. T. & Т.Н. N., pers. obs.).

INTRODUCTION HISTORY

As Sinotaia guangdungensis was initially established in fishponds, the species may have been introduced together with the freshwater fish used to stock these ponds (Johnson, unpub-lished). Various carp species (e.g., Ctenophar-yngodon idella, Hypophthalmichthys nobilis) were imported from Guangdong province in China, and cultivated in ponds across Singapore since the early 1900s (Herre, 1937; Burdon,

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1950). In China, the carp fry were collected
from around villages and transported to ports
in Guangdong province, from which they were subsequently transported to Singapore in tubs containing water from their nursery ponds (Brit-wistle, 1931b). This is likely to have resulted in accidental transfer of other fish species (Alfred, 1966), and even molluscs. The ponds in Singa-pore were ideal habitats for freshwater molluscs as the water was fertilised to enhance the growth of algae for the fish (Britwistle, 1931a: 376). While Sinotaia guangdungensis was well es-tablished in Singapore by the mid-20t century, it did not appear to have been found in neighbour-ing Peninsular Malaysia at the time (Johnson, 1957; 1973). A record of Taia polyzonata in Malaysia by Palmieri et al. (1980) was unveri-fied, as identifications were said to have followed Brandt (1974), who did not include a description of this species. However, in 1995, its presence in Malaysia was confirmed by S. Y. Chan, an amateur malacologist familiar with species from Singapore, and verified to be the same species as the one in Singapore (Chan, 1997). The snail could have been introduced to Malaysia with fish from China, which were transported using similar methods as imports to Singapore (Lin, 1949; Acosta & Gupta, 2005).
To date, Sinotaia guangdungensis has also been introduced to Australia. It was first recorded in New South Wales in 1939, and subsequently in the late 1970s, but populations appear to have declined by the early 1990s (Shea, 1994). Since the late 19th century, fish introductions have been common in southeastern Australia, where early settlers stocked water bodies with European carp and other imported fish, includ-ing some from Singapore (Koehn et al., 2000). Itis possible that Sinotaia guangdungensis may have also been introduced to Australia with such shipments of fish, either from China or even from Singapore. Accidental introductions are complex and usually difficult to resolve (van Leeuwen et al., 2013). A recently established population of the congeneric Sinotaia quadrata (Benson, 1842) in Argentina was also likely to have been accidentally introduced (Ovando & Cuezzo, 2012). Nonetheless, further work to compare the population genetics of native and introduced Sinotaia guangdungensis may help explain the routes of introduction (Ficetola et al., 2008; Hayes et al., 2008).

CONCLUSION

The introduced viviparid species with a spirally ribbed shell in Singapore that has been referred to in the literature as Vivipara polyzonatus, Viviparus polyzonata and Taia polyzonata, is now more appropriately called Sinotaia guangdungensis (Kobelt, 1906). While it has been established in Singapore for more than half a century, Sinotaia guangdungensis has not caused any discernible impacts in the natural environment, perhaps owing to its distribution being restricted to artificial or more modified habitats. Molecular and ecological studies of Sinotaia guangdungensis in Singa-pore are needed to identify introduction routes, and potential traits or environmental factors that have enabled it to establish so successfully here. Further study of the populations here would not only provide valuable insight into the mechanisms through which freshwater mol-luscs have been introduced and established in Singapore’s novel freshwater habitats (e.g., reservoirs), but may also aid in the manage-ment of these habitats.

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